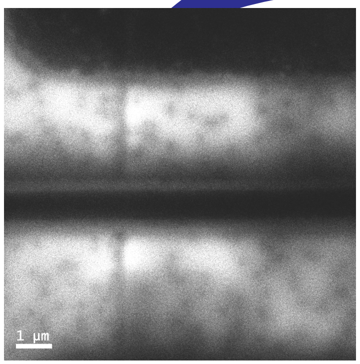
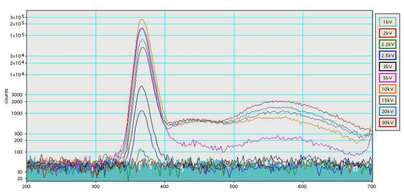
CL and PL Characterization

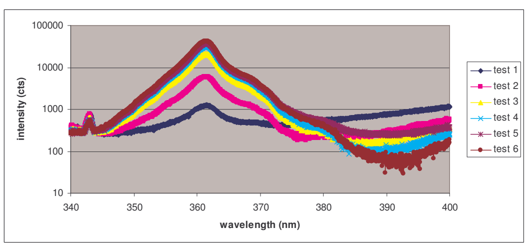
FLOORS



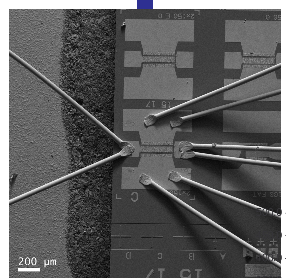
CL on pre stressed device



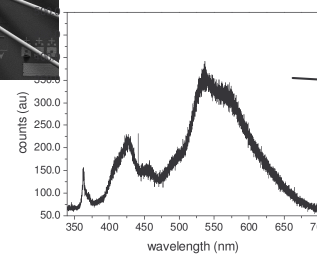
CL depth profiling

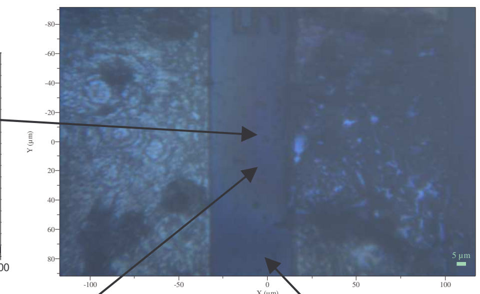


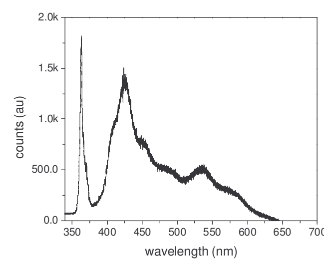
PL on bulk epi and pre stressed devices

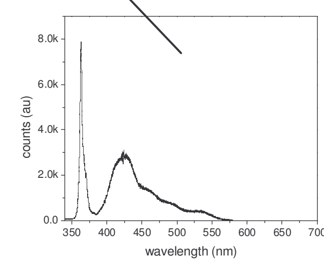


PL on post stressed devices









t=0, As Built

t>0, Degradation

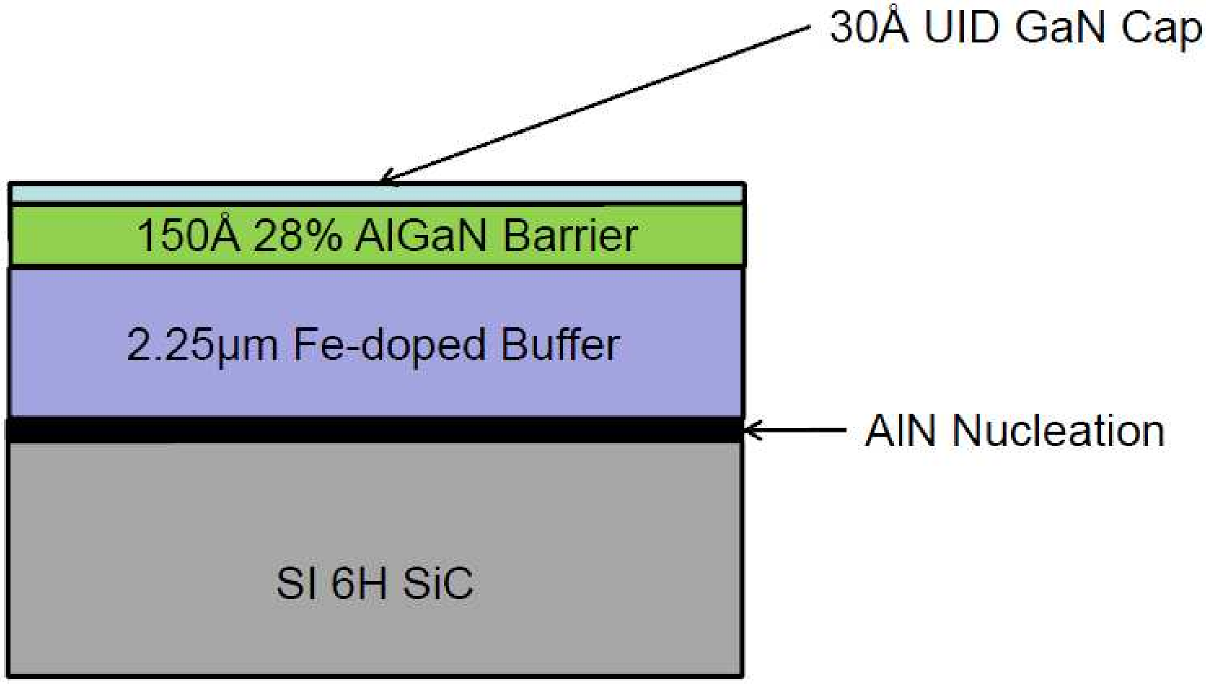
Cathodoluminescence and Photoluminescense of AlGaN/GaN devices

5/5 - 5/6 2011

Danny Zeenberg, Midori Maeda,
Brent Gila, Cammy Abernathy

Device

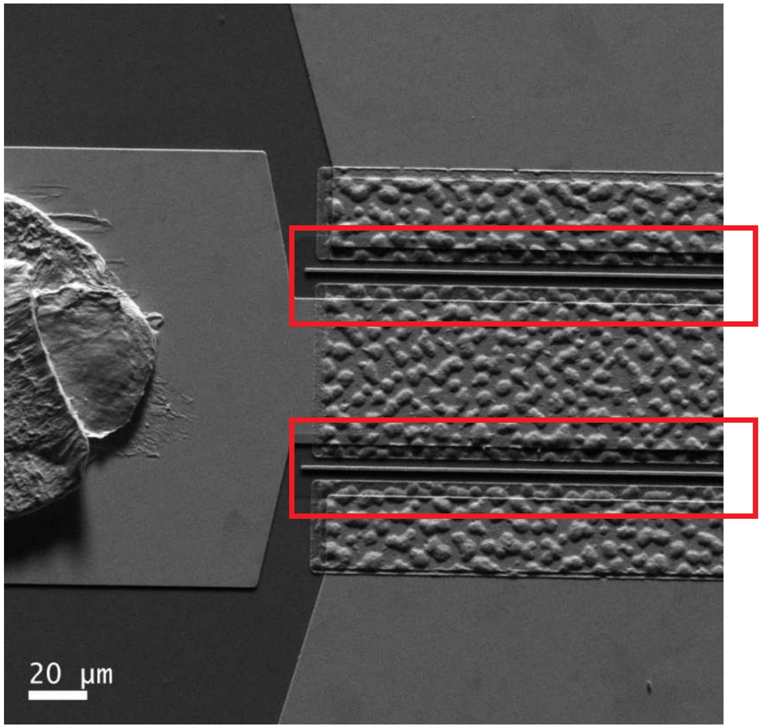
- Our devices are built on the substrate illustrated below.



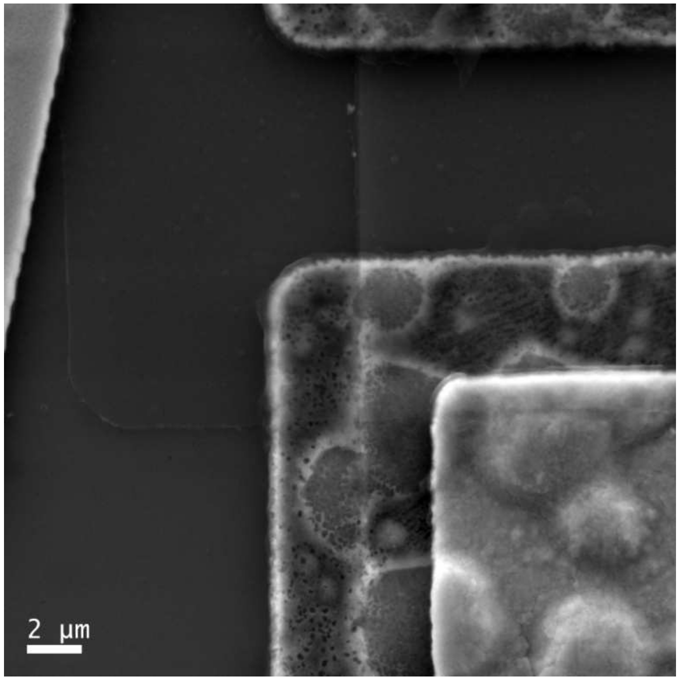
Cathodoluminescence Experiment

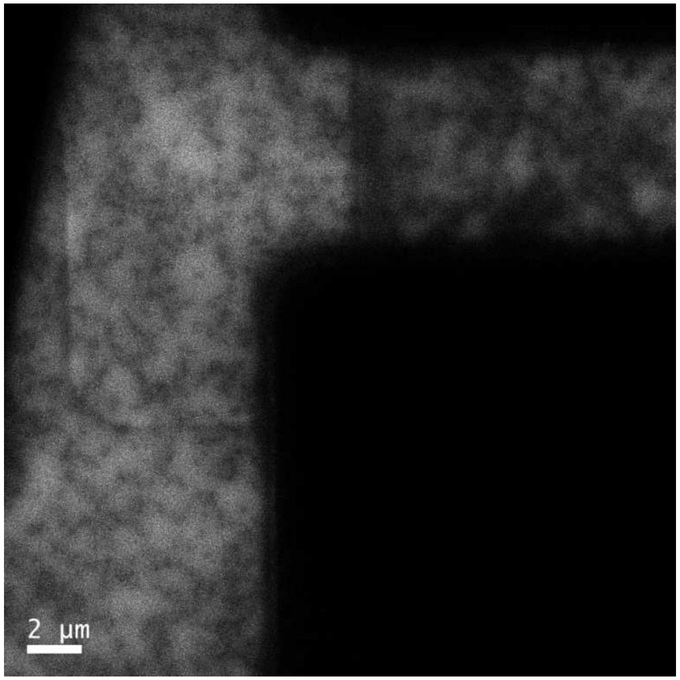
- Analysis is done before and after failure
- Area of interest is in the channel/gate region

- Accelerating voltages were varied from 1keV to 30keV



Substrate Defects



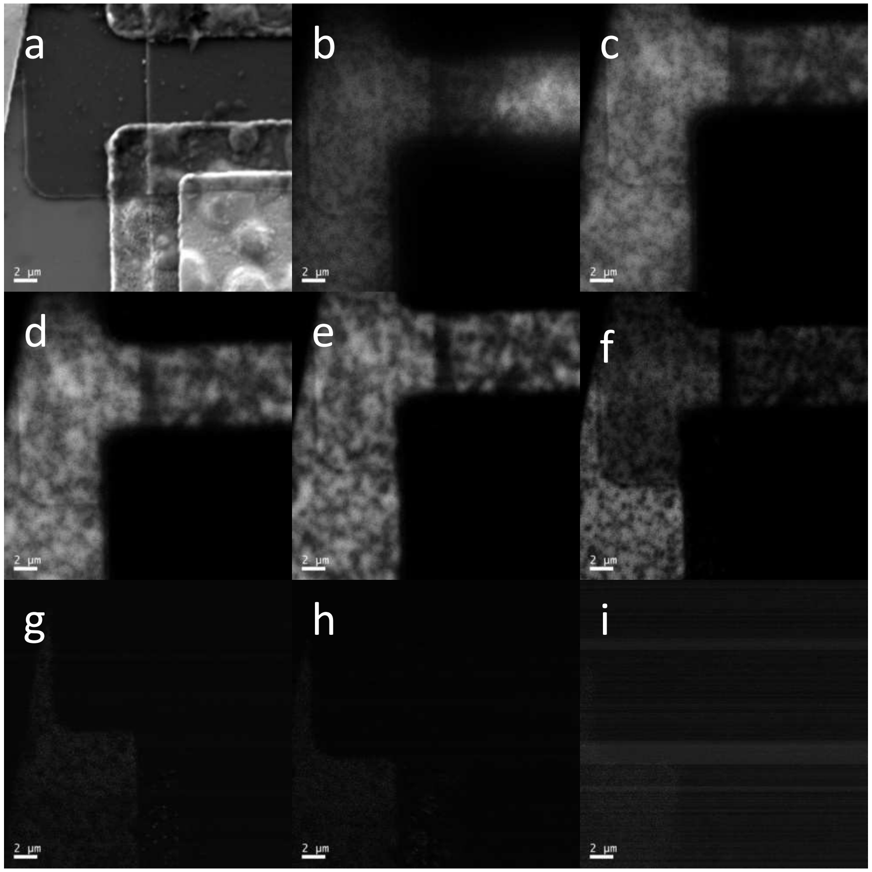


20kV 10kx SE and CL Images

- Defects identified as threading dislocations terminating at the surface[1]

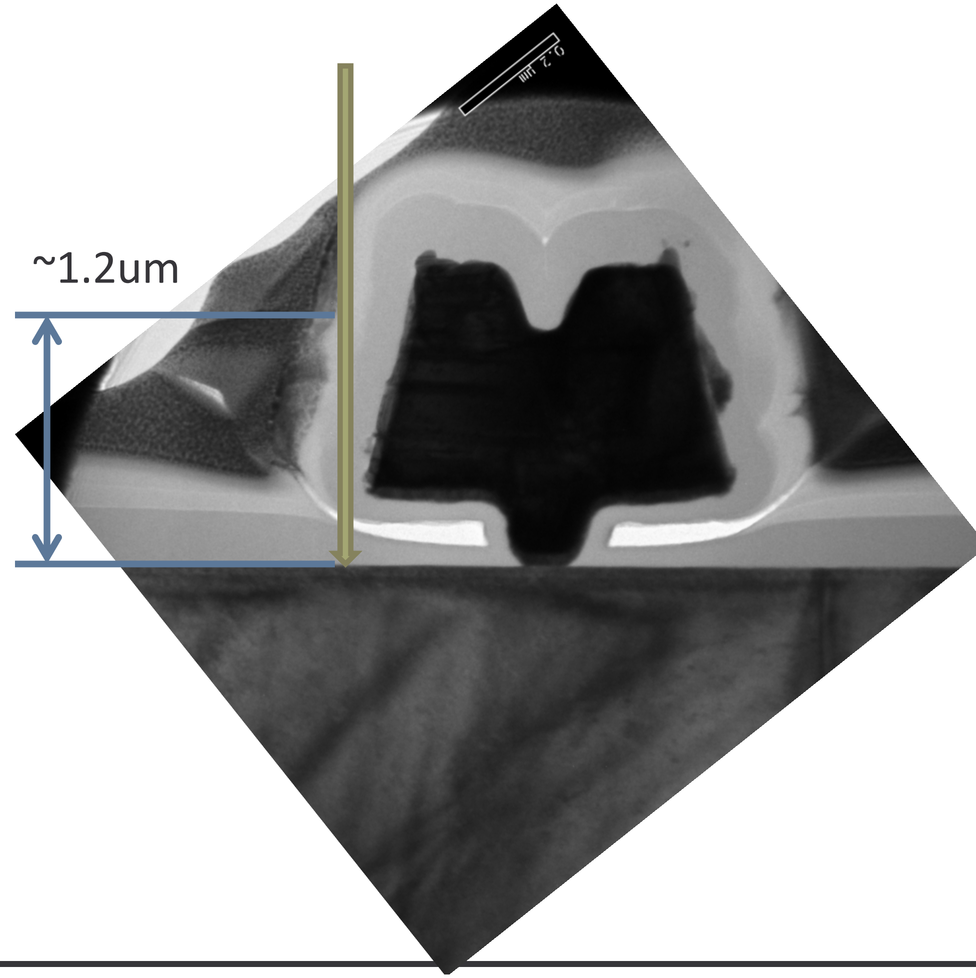
Depth Dependence of CL Signal

a) SE image 10kx
b) 30kV CL image
c) 20kV CL Image
d) 15kV CL image
e) 10kV CL Image
f) 5kV CL image
g) 3kV CL image
h) 2kV CL image
i) 1kV CL image



Passivation Layer

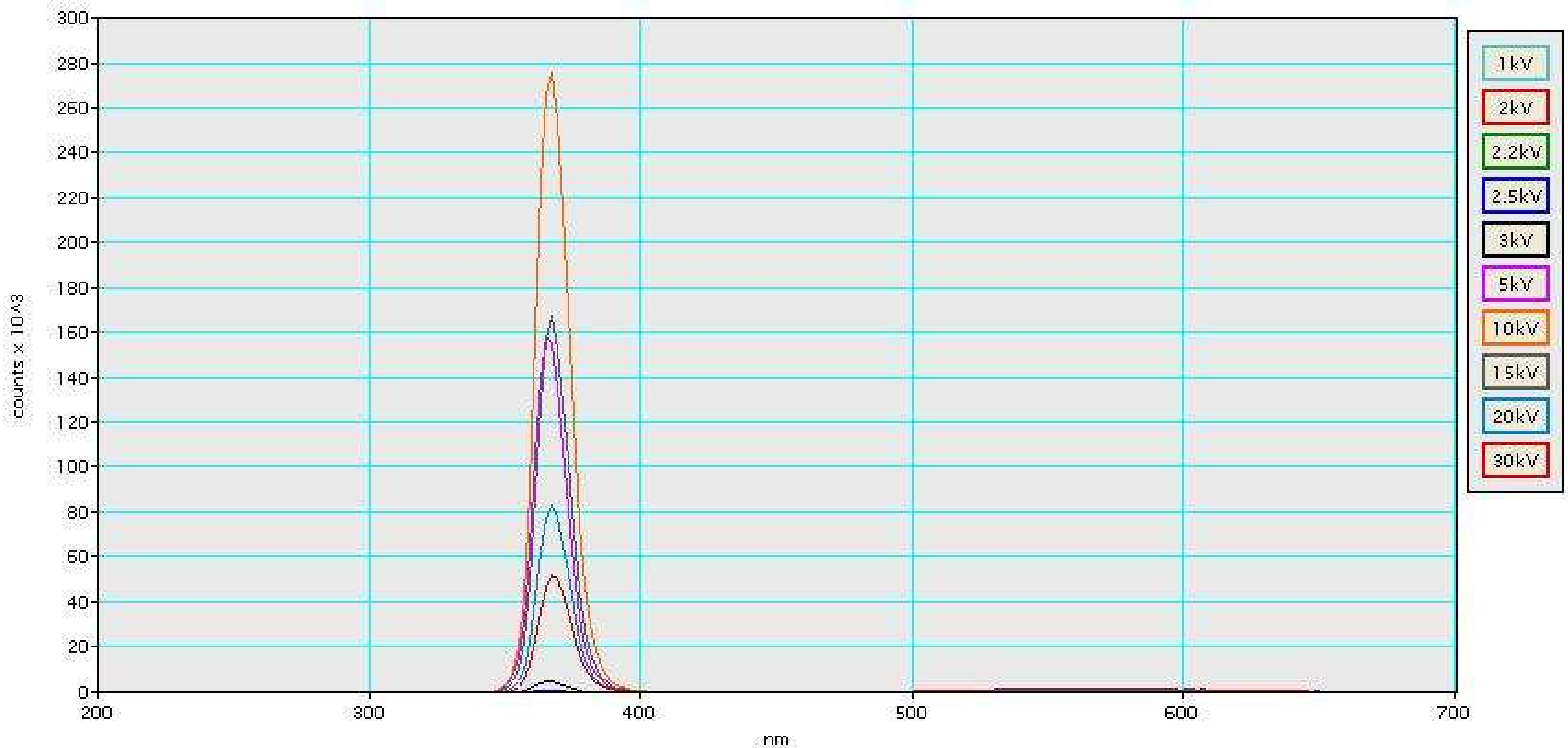
- Passivation layer makes it difficult to estimate actual penetration depth
- Lack of intensity at low voltages attributed to film thickness
- Thin film layer underneath is shielded



Monochromatic Spectroscopy

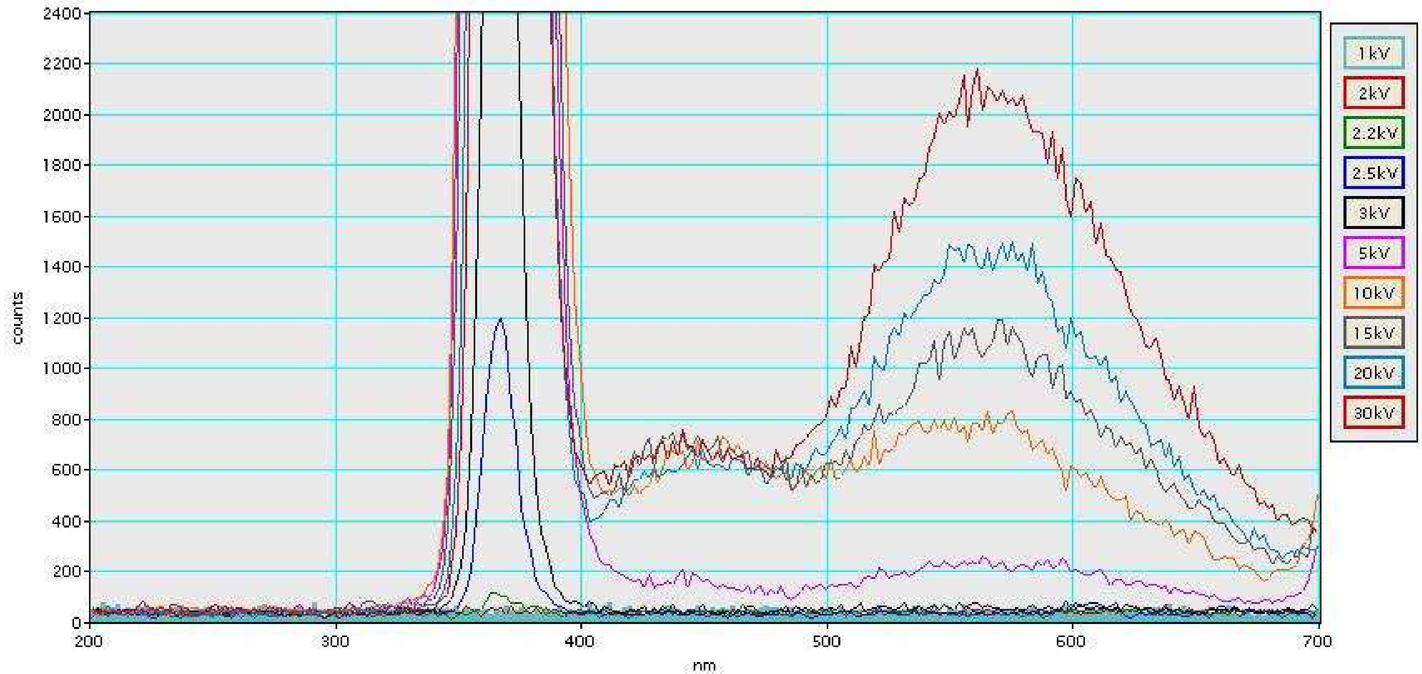
- Accelerating voltages
  - Varied from 1kV to 30kV
- Wavelengths scanned
  - Spectrum from 200nm to 700nm
- In theory the range will give us penetration depths from 8nm to >3μm

GaN Band Edge Peak



- GaN Band Edge shows a maximum signal at 10keV or ~500nm
- The ratio of defect to band edge peaks increases rapidly after 10kV indicative of the higher defect densities deeper in the sample[2]

Defect Peaks



- Yellow (556nm) and blue (440 nm) luminescent signals are visible defect peaks
- The Blue defect is stationary until we drop to 5kV while the Yellow defect increases steadily with voltage

Conclusions

- Threading dislocations are present at all visible accelerating voltages and are known to be non-radiative defects[3]
- Deeper defects contribute to the yellow and blue bands visible in the spectra
- Depth dependence and passivation layer thickness have a significant effect on signal strength and the wavelengths detected

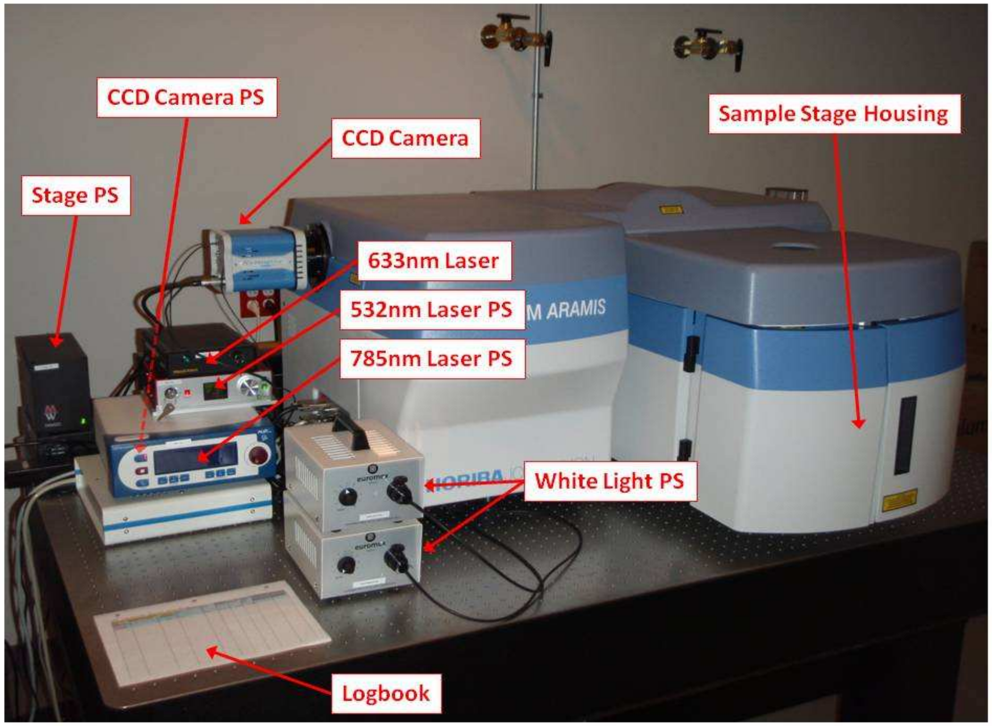
Photoluminescence Experiment

- Photoluminescence was conducted on the Horiba MicroRaman tool utilizing the 325nm He-Cd laser
- A previously stressed device was measured to attempt to locate the degraded portion of the channel and identify any underlying defect spectrum

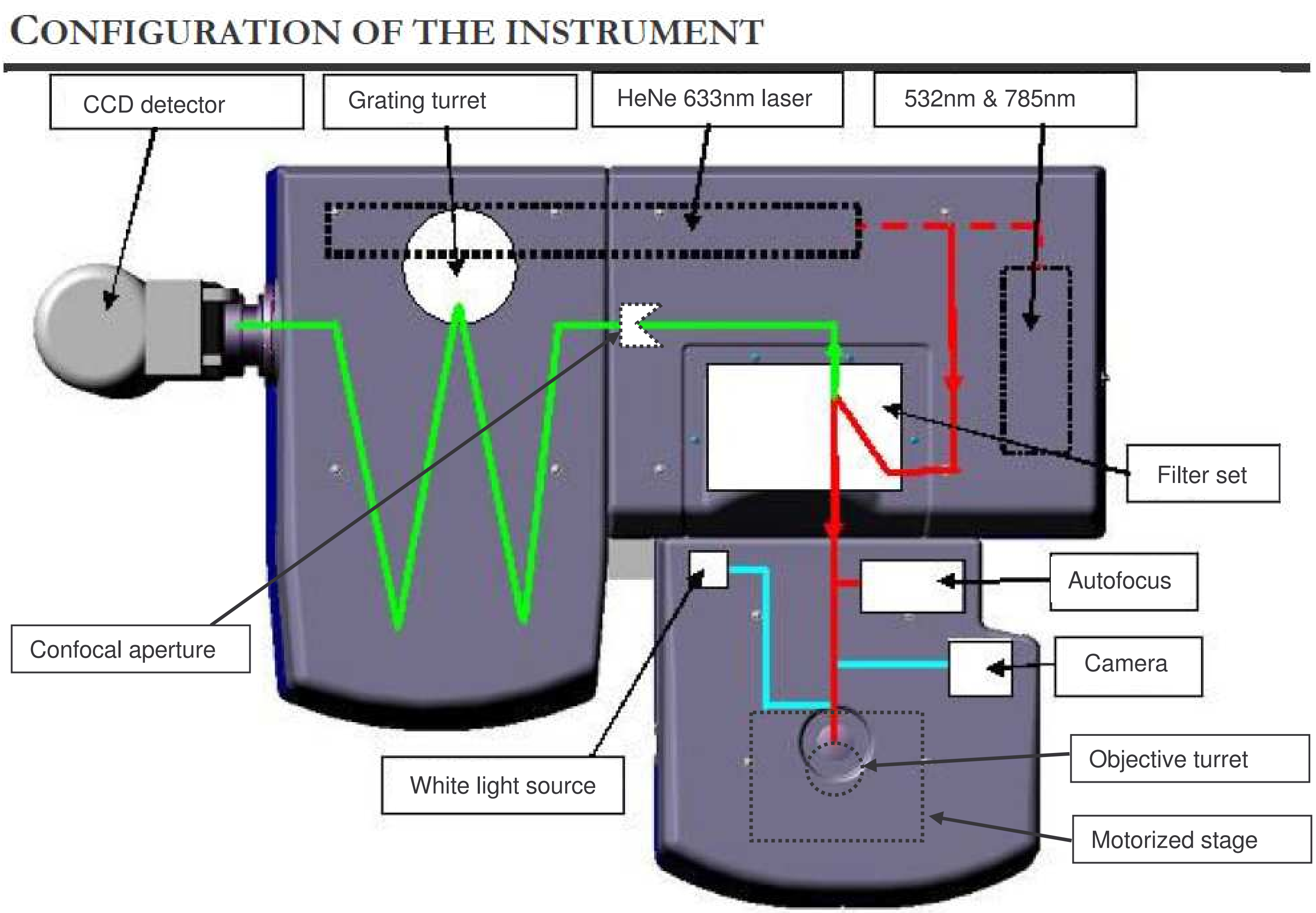
Horiba Aramis LABRam system overview

The Aramis Raman system is a software selectable, multi-wavelength Raman/PL system with mapping capabilities, a 400mm monochromator and CCD detector. Mapping is possible through a motorized stage for mapping with “autofocus” and DuoScan laser rastering for mapping within the objective field of view. Internal steering optics are mirror based for increased UV capability.

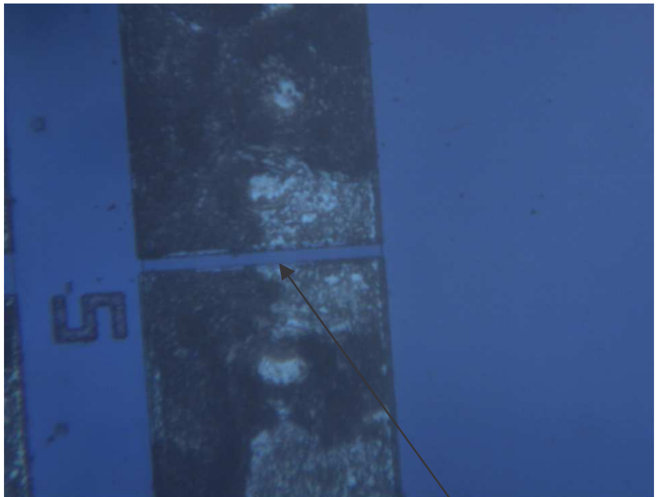
System specs:
Lasers: 325nm, 532nm,
633nm, 785nm
Gratings: 300g/mm, 600g/mm,
1800g/mm, 2400g/mm
Objective lens: 10x, 50x, 100x,
40x (for UV work)

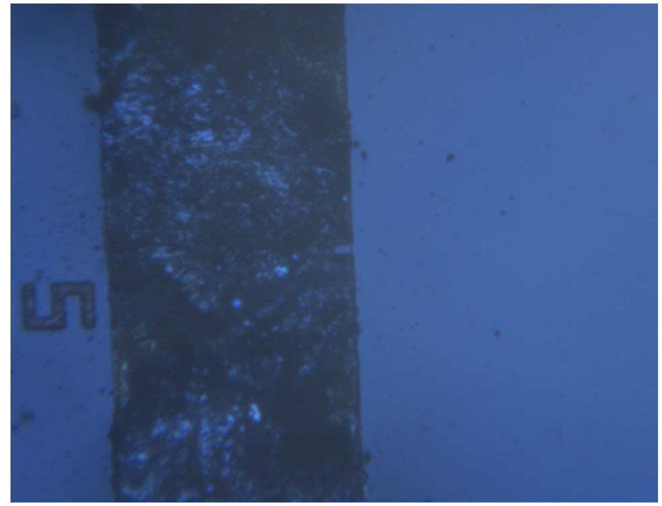


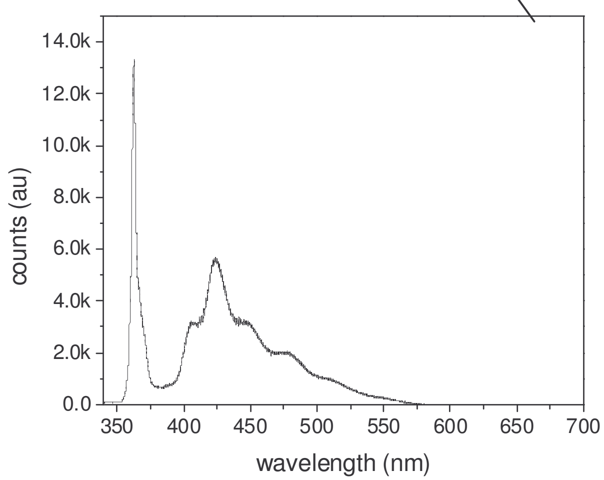
Horiba Aramis LABRam system overview



Conventional AlGaN/GaN HEMT TLM analysis

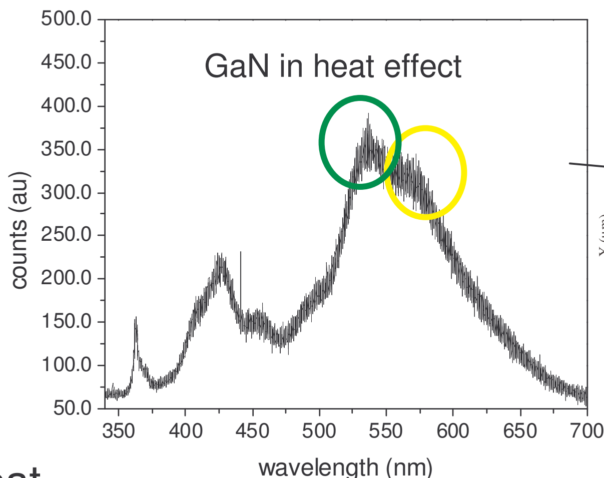


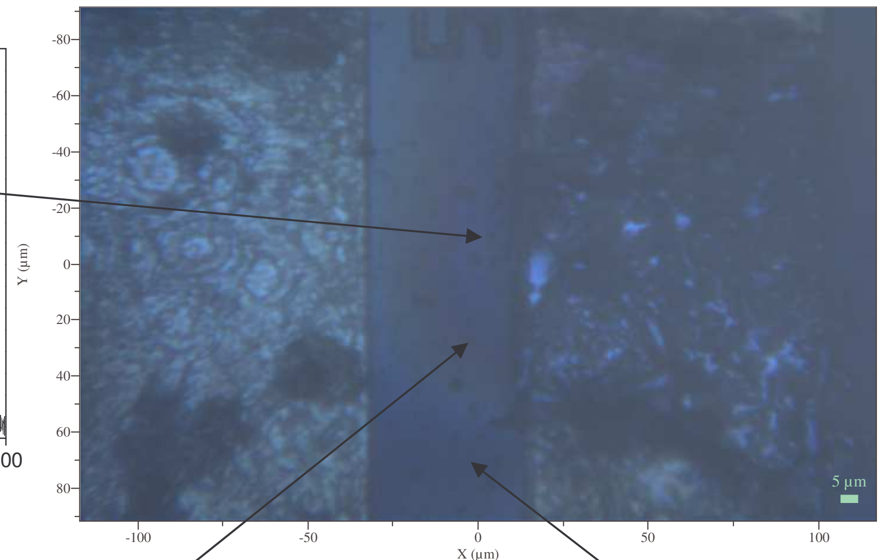




Post stress shows catastrophic failure and metal covering the channel

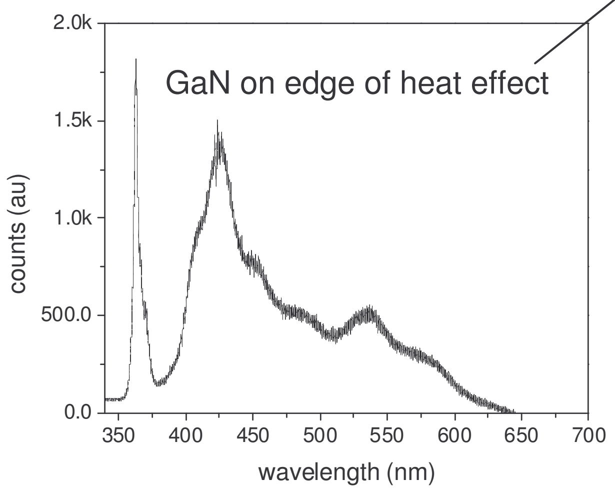
Conventional AlGaN/GaN HEMT TLM analysis

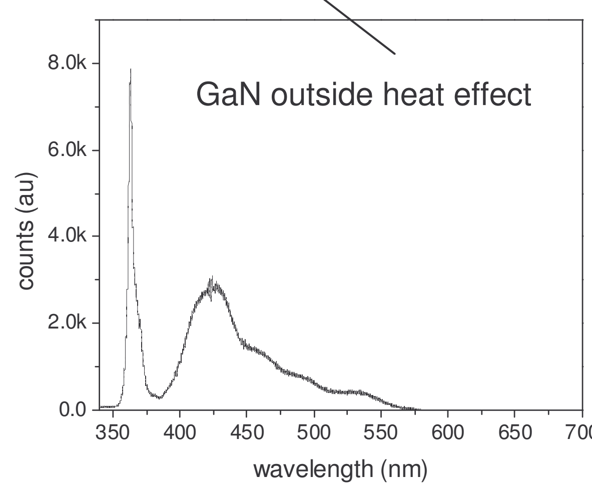




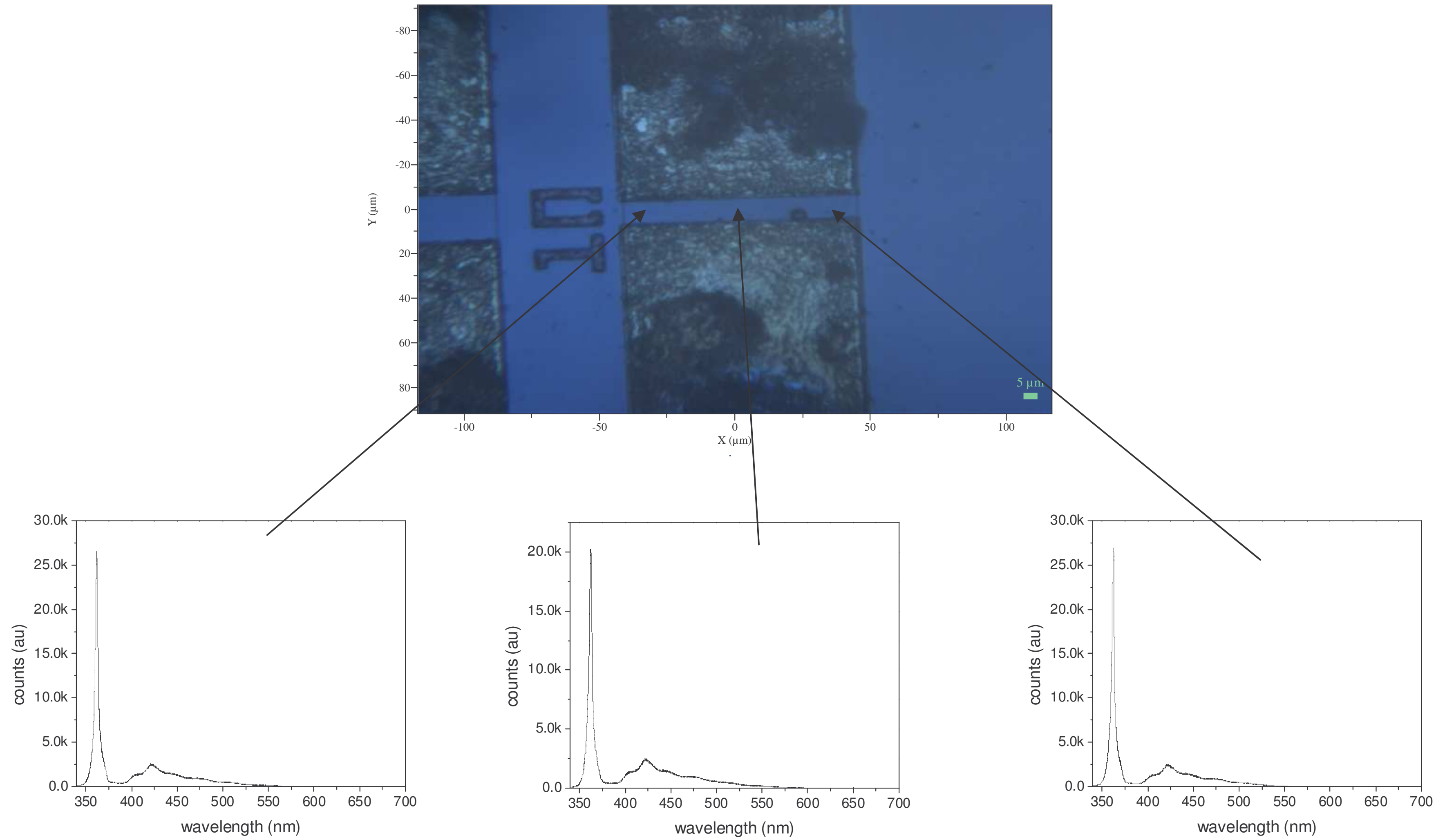
Analysis of heat effected region on side of ohmic contact.

Evolution of green and yellow defects due to extreme contact heating.

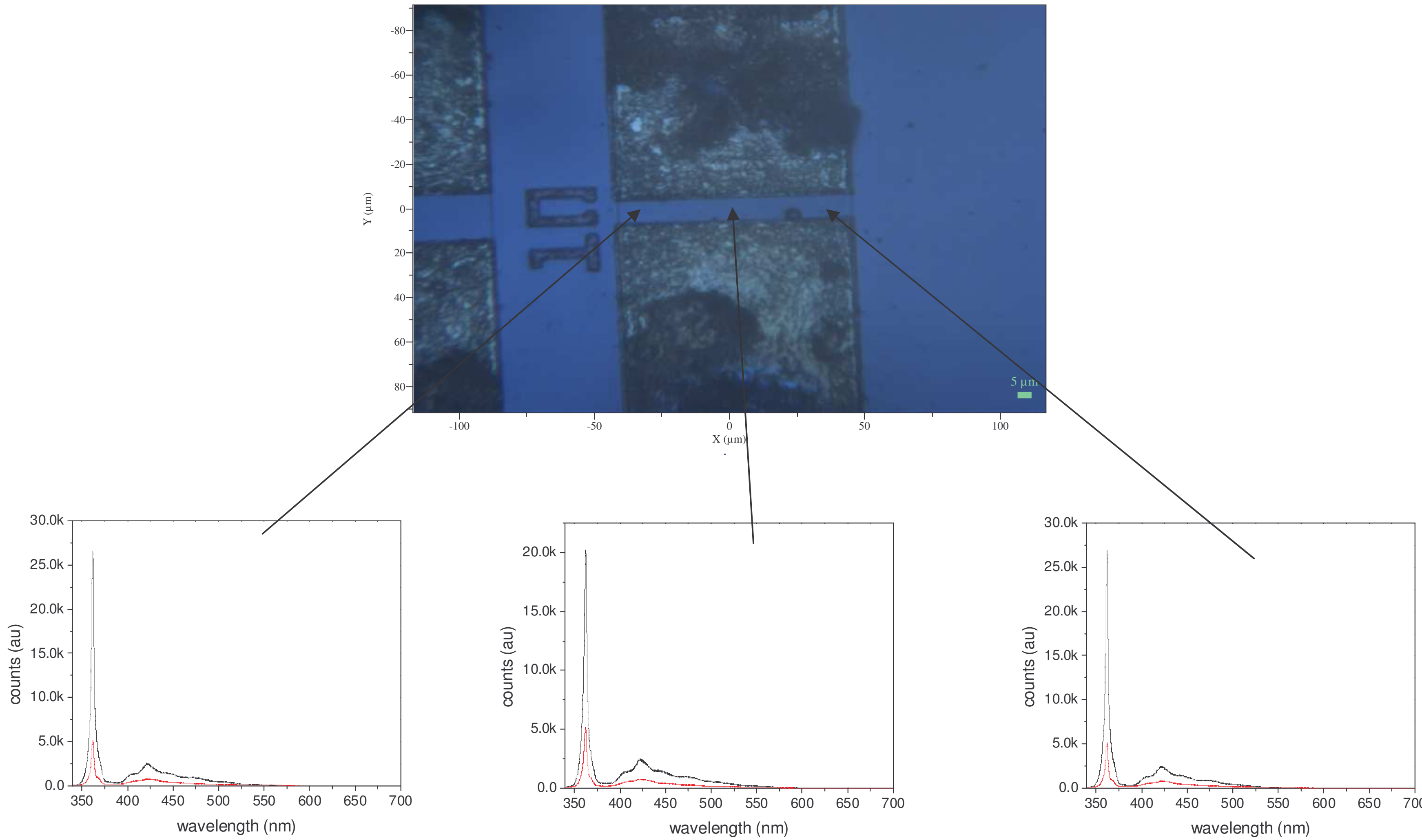




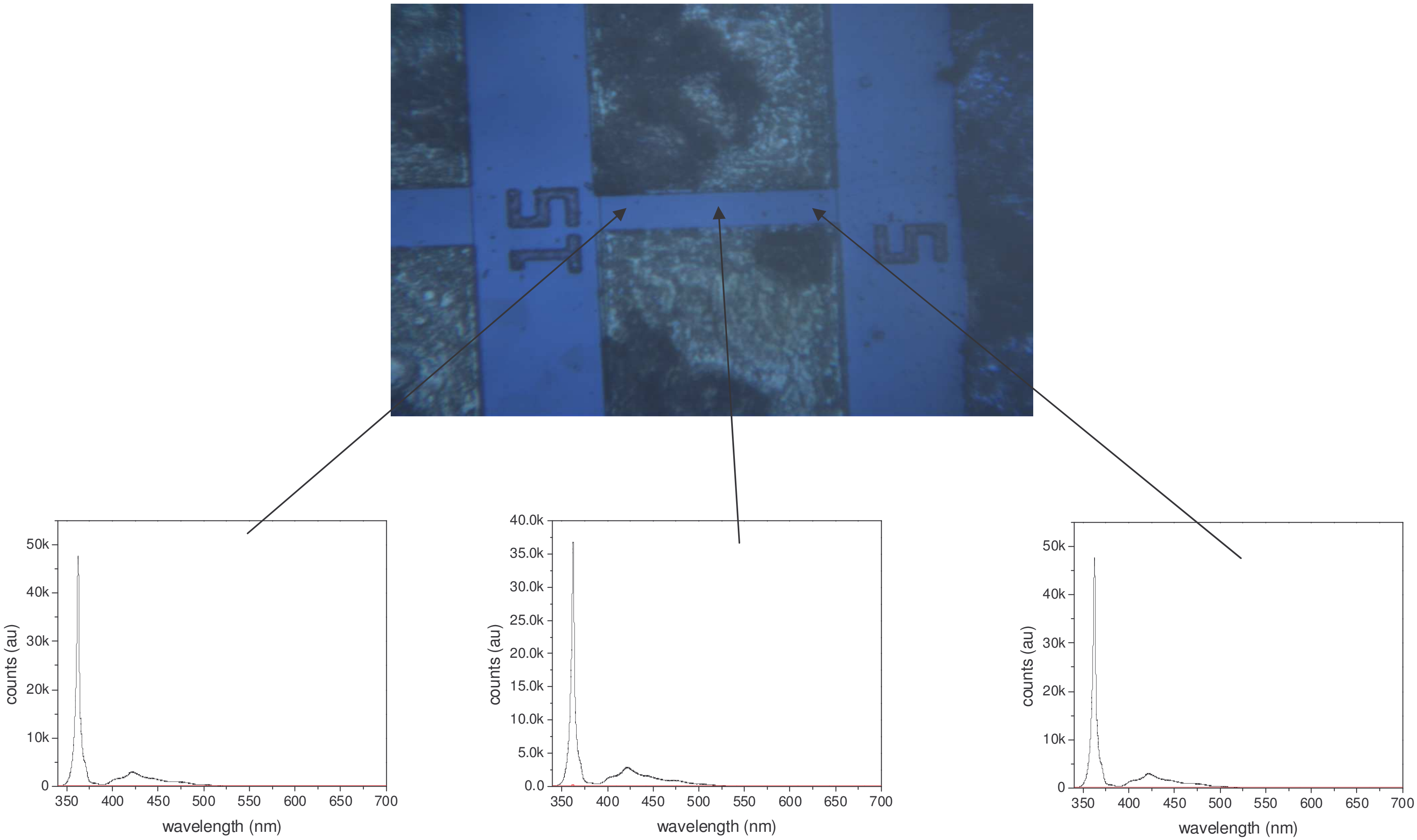
Conventional AlGaN/GaN HEMT TLM analysis



Conventional AlGaN/GaN HEMT TLM analysis



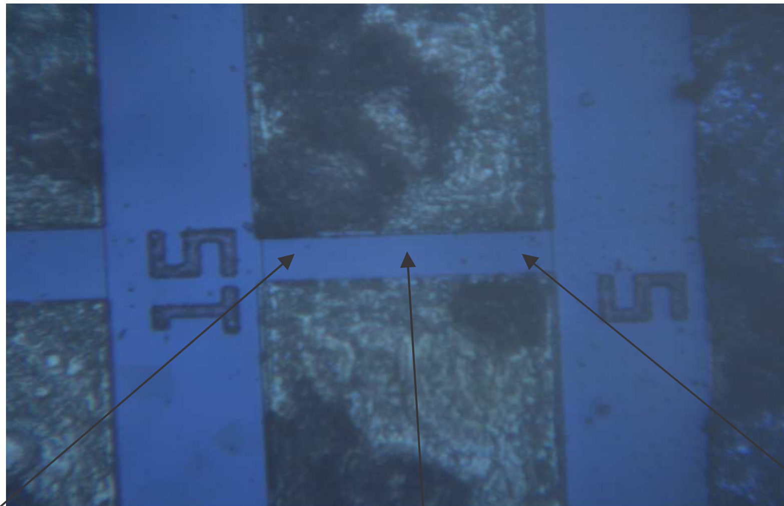
Conventional AlGaN/GaN HEMT TLM analysis

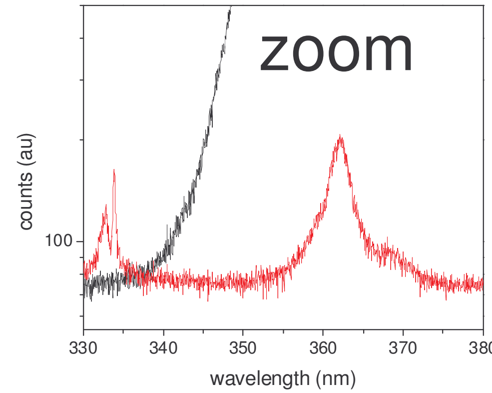


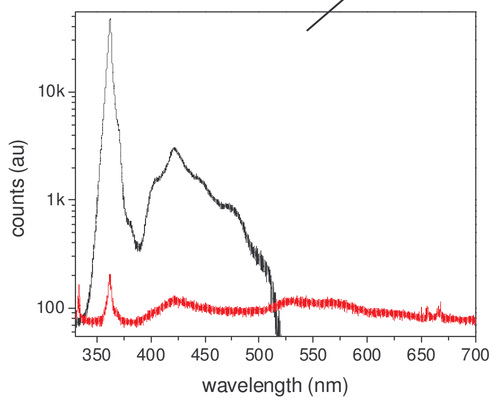
Conventional AlGaN/GaN HEMT TLM analysis

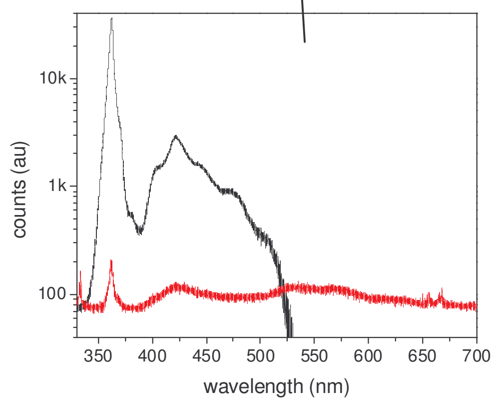
In log scale, a higher energy peak is seen post stress. Associated with an AlGaN layer…but which one?

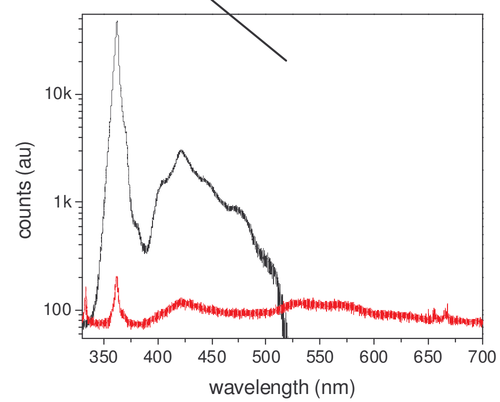
332.9nm = 3.72eV
333.8nm = 3.71eV
~$Al_{0.11}Ga_{0.89}N$





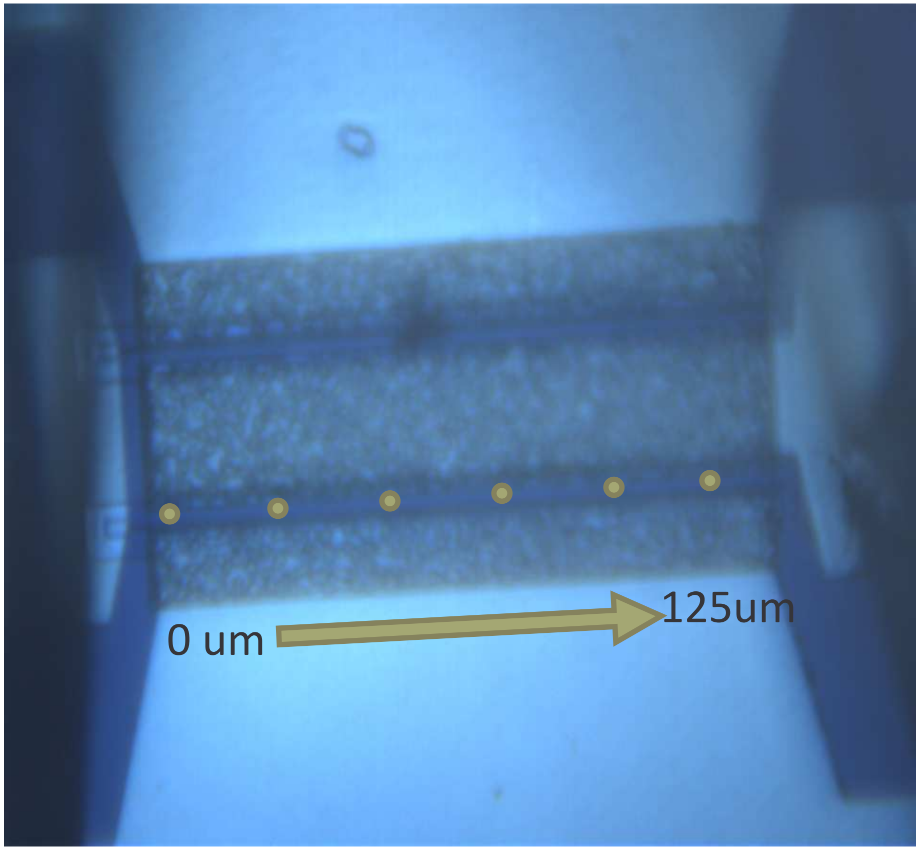




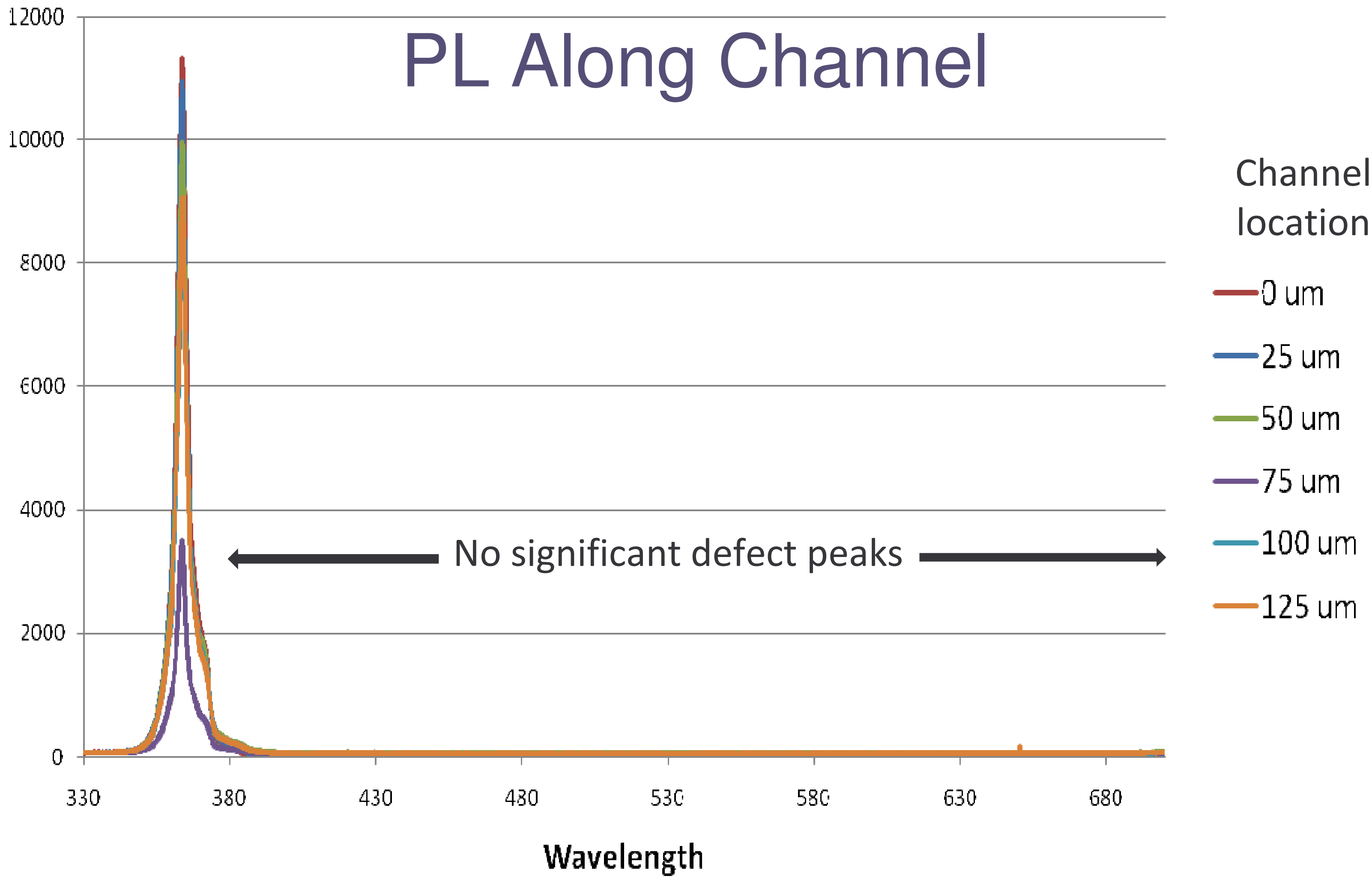


AFRL AlGaN/GaN HEMT device analysis

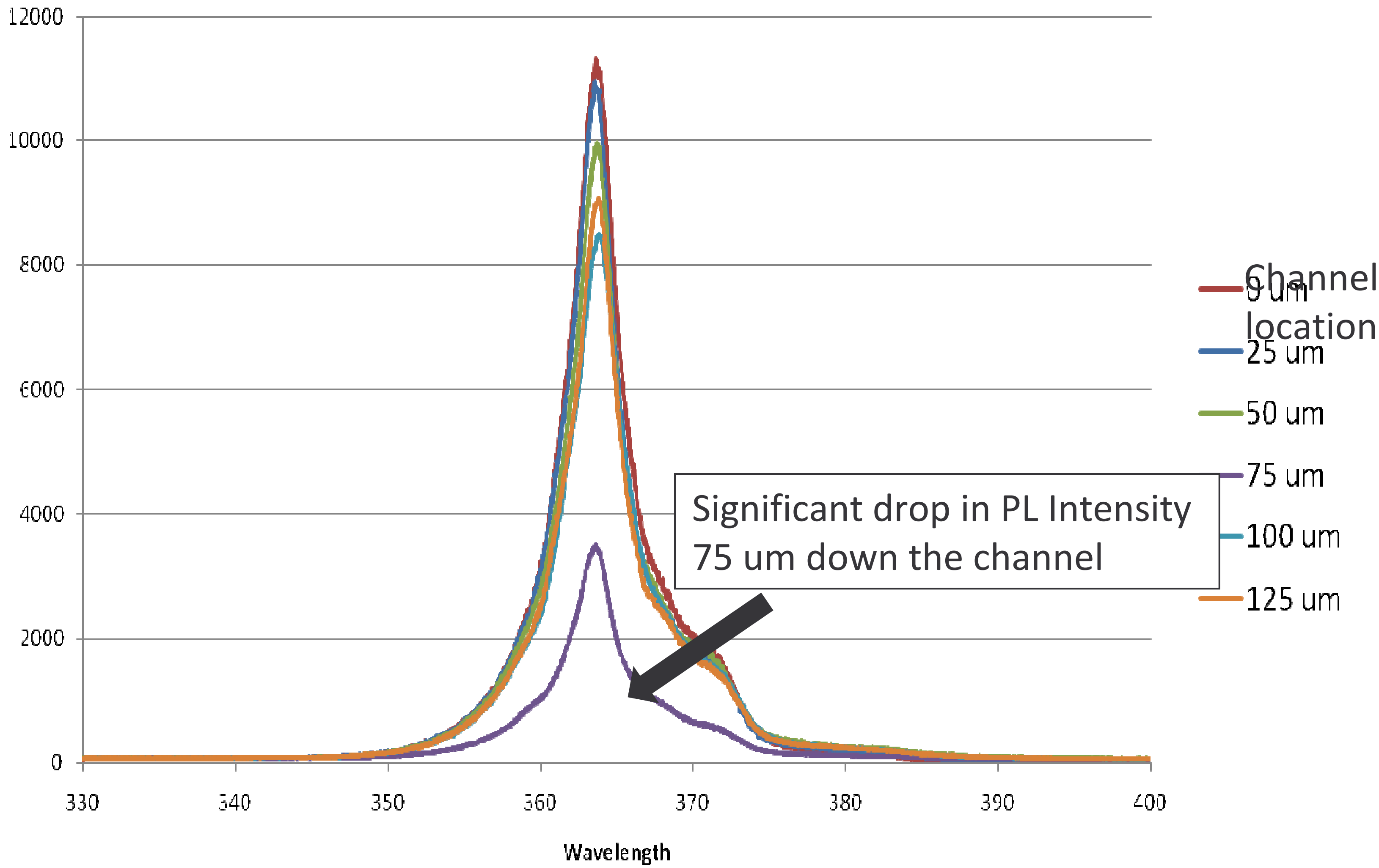
1. 0 um
2. 25 um
3. 50 um
4. 75 um
5. 100 um
6. 125 um



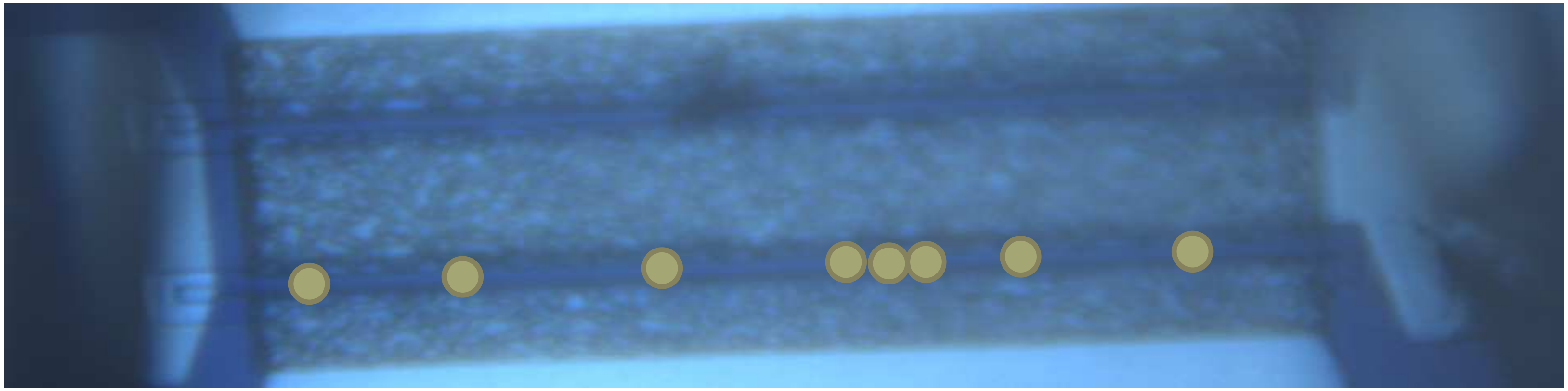
AFRL AlGaN/GaN HEMT device analysis



AFRL AlGaN/GaN HEMT device analysis

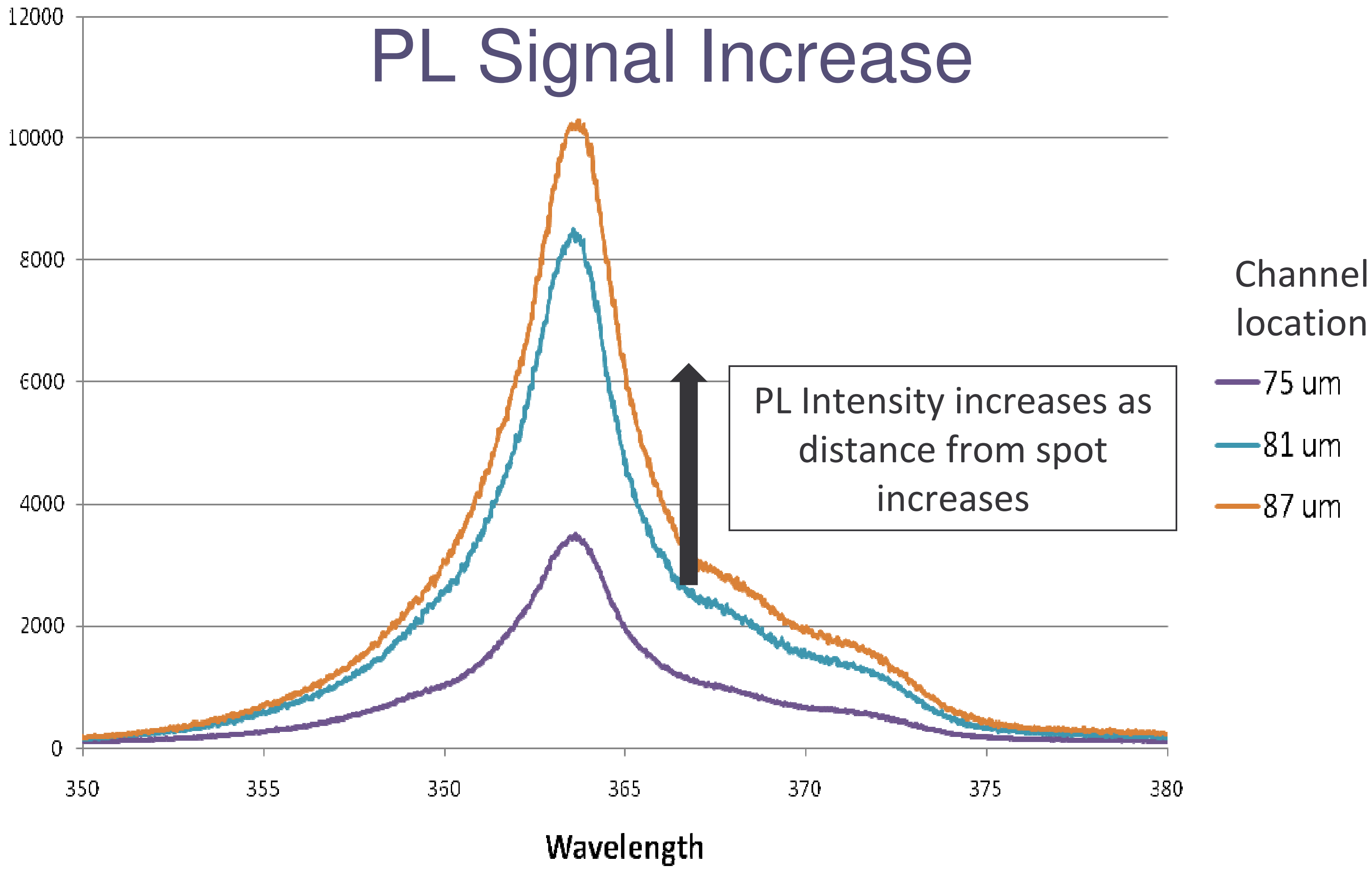


PL Spot Size to Scale



- Approximate spot size and locations are shown above
- Spot size reduces accuracy but gives better qualitative results than CL because of area coverage

AFRL AlGaN/GaN HEMT device analysis



PL Conclusions

- Larger laser spot size (compared to CL) gives better indication of degraded areas
- Both CL and PL results imply non-radiative defects are the cause of post-stress degradation
- TLM degradation shows a non-typical AlGaN layer developing during channel stress
- PL can be used as a locator for hi-res CL and XTEM work
- Further depth dependent PL will be done to correlate depth to CL study

References

1. Rosner et al, *Appl. Phys. Lett.*, Vol. 70, No. 4, (1997)
2. Reshchikov et al, *Phys. Rev. B*, Vol. 64, 115205 (2001)
3. Hino et al, *Appl. Phys. Lett.,* Vol. 76, No. 23 (2000)